Micro-Meteoroids: Effects on Space OTE Optics

Lester M. Cohen/SAO

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Presented by H. Philip Stahl, MSFC

Study Plan & Initial Results

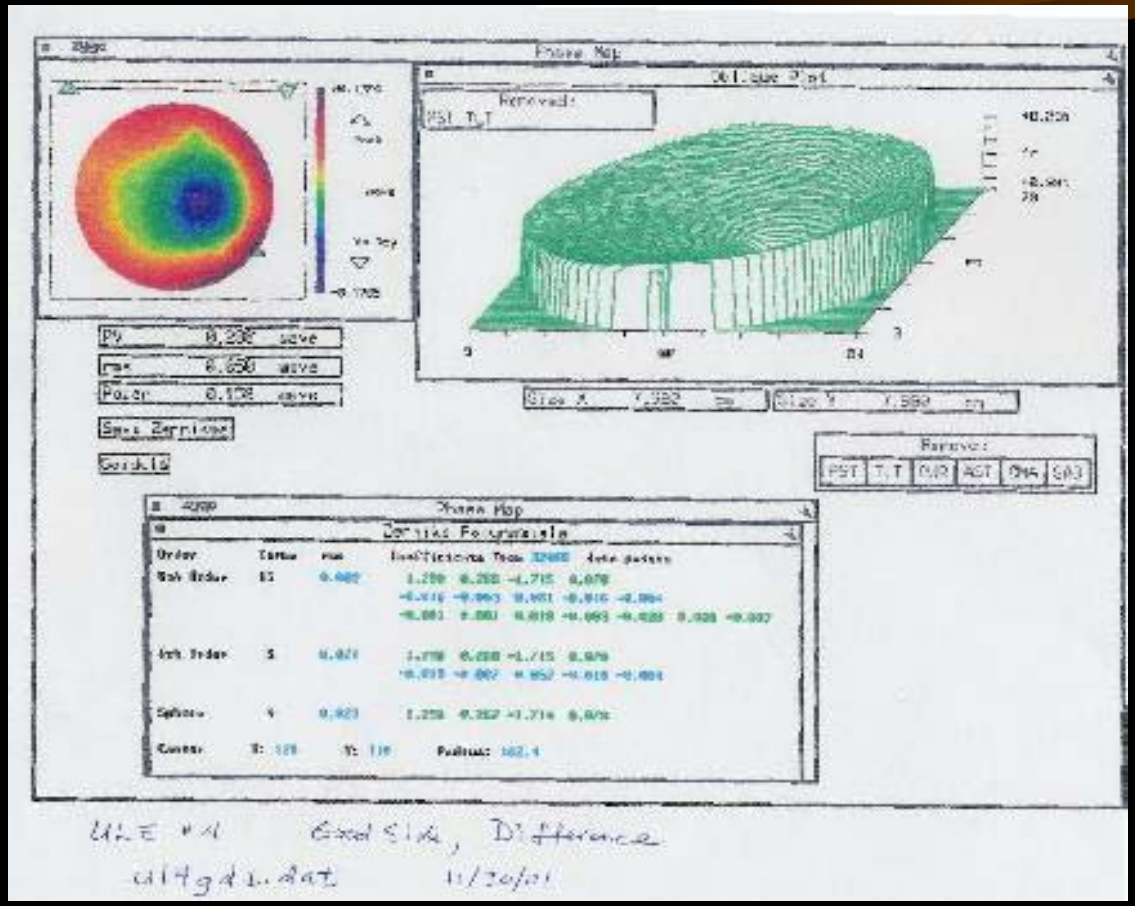
- *Plans' Intent*
  - Determine what if any non-correctable figure changes occur to the OTE optics due to μM impacts.
- *Plan consists of*
  - Sub-scale test coupons
    - Complete
  - Numerical simulation
    - Partially Complete
  - Larger scale mirror simulators
    - In-Process
  - Other (indentation, etc)
    - TBD

L2 Environment

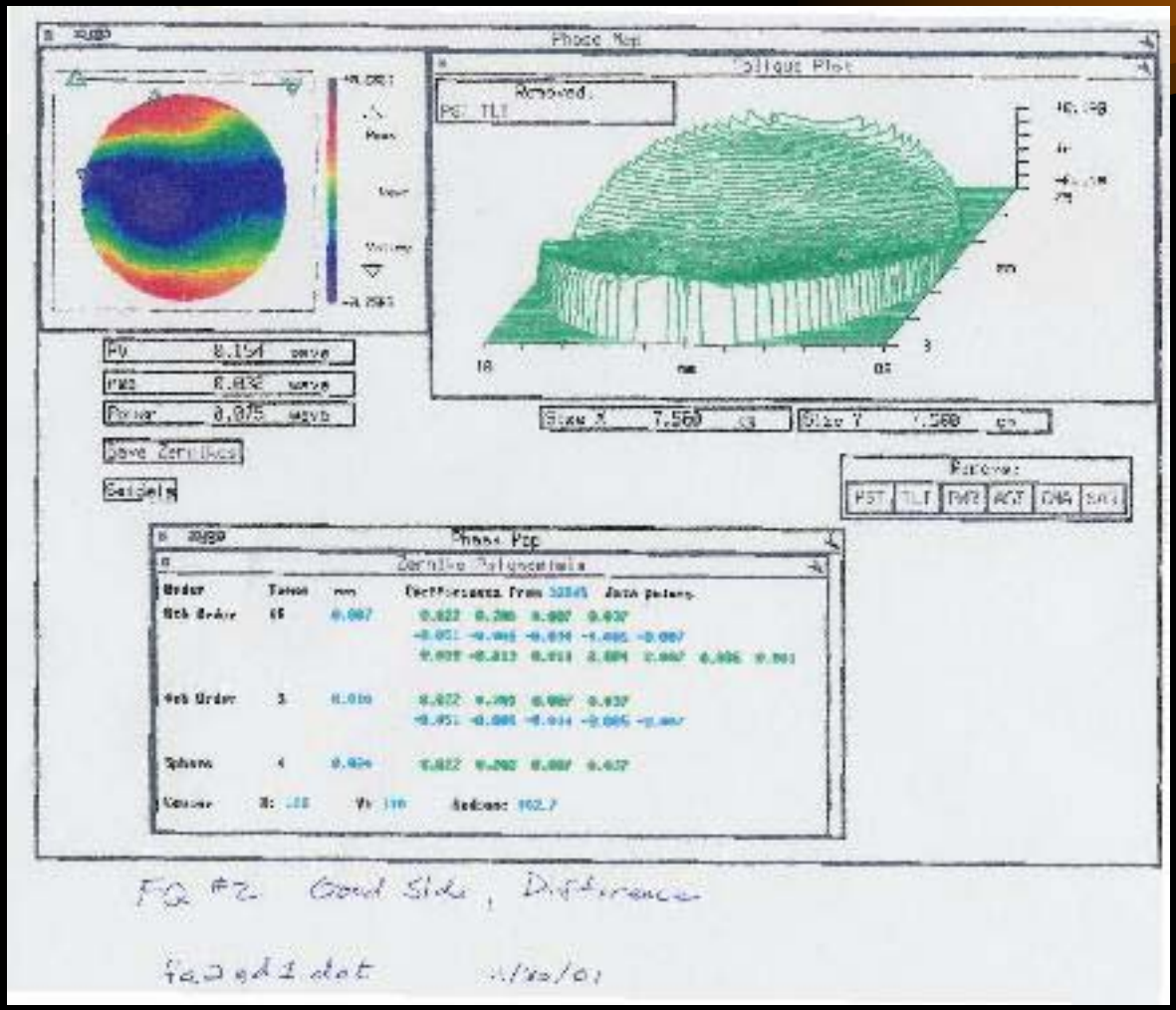
- Micro-meteoroids
  - Velocities: > 20km/s
  - Size: less than 0.5um > few mm's
  - Flux: ~2600/m^2/yr for ~0.5um to ~1/m^2/1700 yrs for ~1mm

Geometry Showing Initial Test Set-Up
Tests Performed at Auburn University Hyper-velocity Test Facility

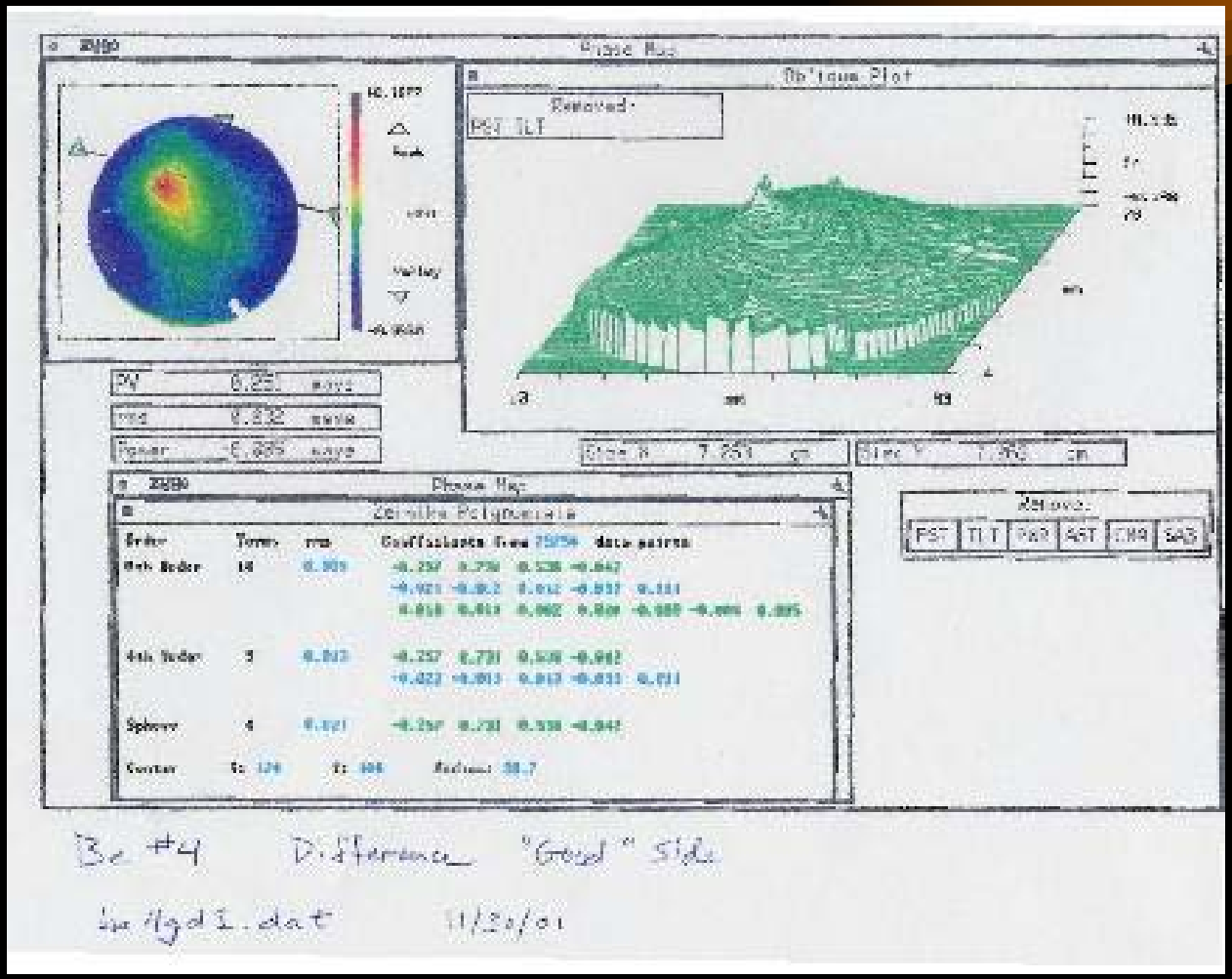
Typical Geometry *Changes*
Fused Silica Sample



Typical Geometry *Changes*
ULE



Typical Geometry *Changes* Beryllium



Percentage of Kinetic Energy Hitting Test Disks vs Predicted Total Kinetic Energy (after 10 years)

Be-4	Be-3	FS-2	FS-3	ULE-4	ULE-1
~25%	~18%*	~34%	~17%	~140%	~3.8%

*Based on an assumed avg. vel of 7.75km/s

Streak Camera does not capture all events, thus these percentages are under estimates of actual.

How Did We Go From Kinetic Energy to Predictions of Surface Figure Change ?

- Using the calculated KE per 75mm test disk over a 10 year life, we scaled the “power term (only)” from our 75mm disk tests to come up with a “power change” for a freely supported 75mm disk.
- Using the P-V calculations from above, we calculated an equivalent bending moment “M” in a 75mm disk that would cause the same P-V deformation.
- This bending moment “M” was imparted as a “skin stress” (aka bi-metallic bending).
- This same “skin stress” was then imparted to a single cell from each AMSD mirror. Symmetry boundary conditions were assumed (the same thing happens to each cell). The cell P-V were obtained !
- Global “Power” Changes are for the most part “correctable” !

Predicted P-V Deformations Within AMSD Unit Cells Considering Only The "Power" Changes Found in Our Sample Testing To Date

Architecture/Material	Unit Cell P-V (nm)
Ball Beryllium	0.6 to 1.1
Goodrich Fused Silica	1.3 to 3.2
Kodak ULE	0.1 to 1.4

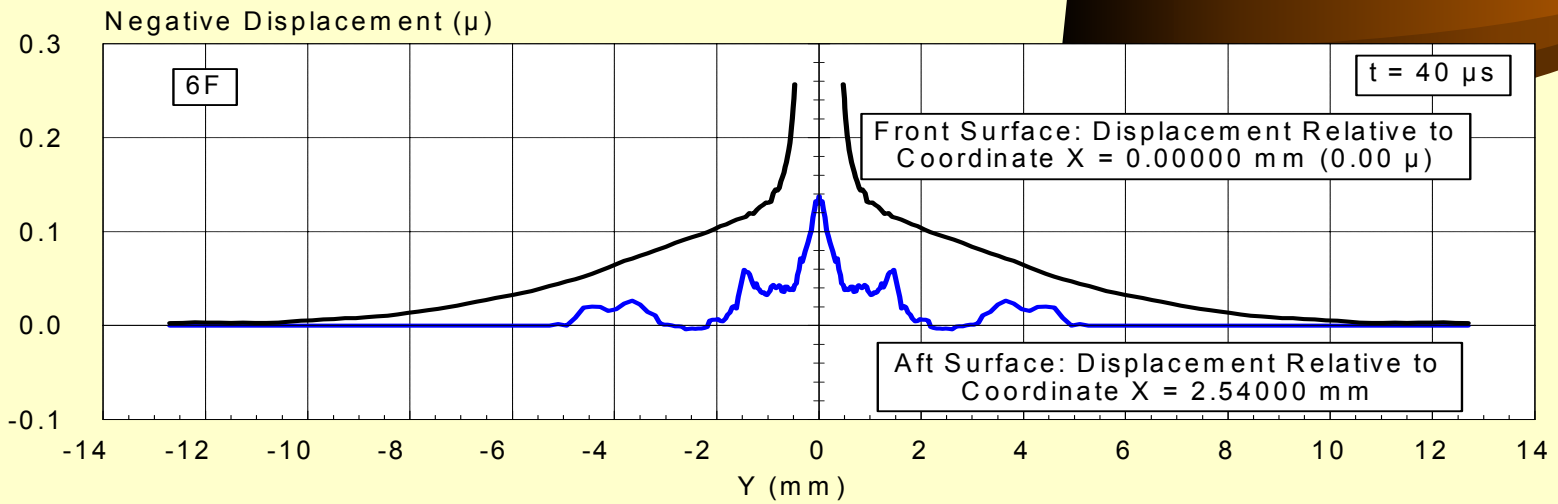
Numerical Modeling Simulation

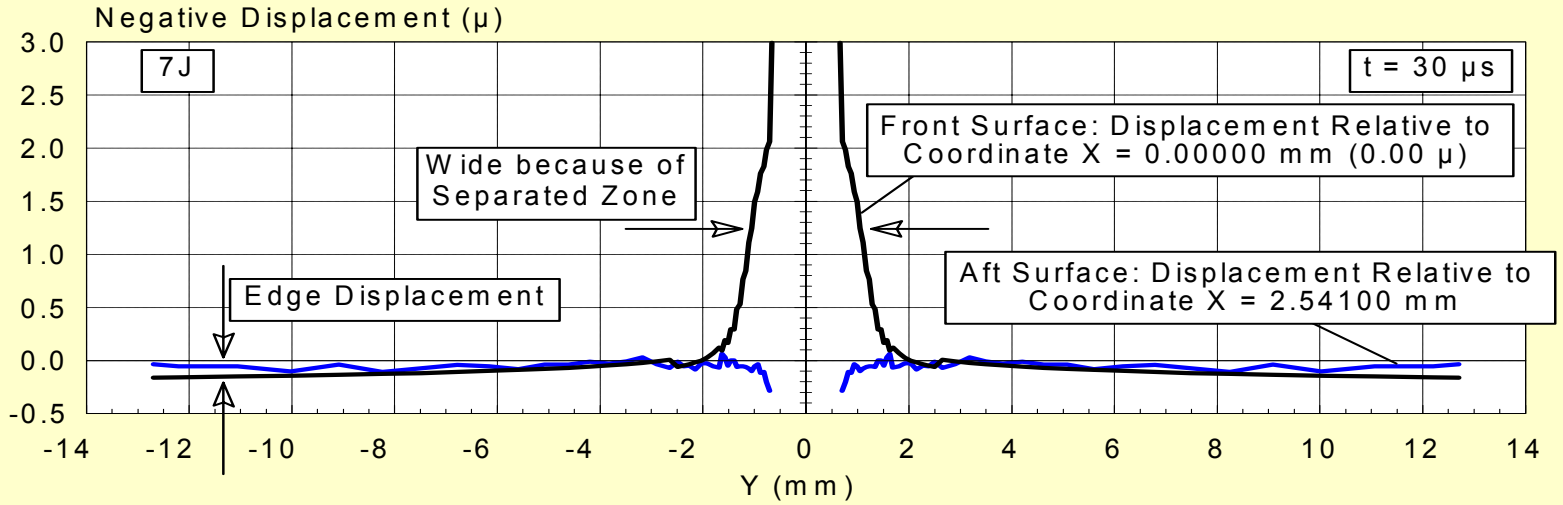
- Shock Transients Inc. (Dr. David Davidson)
  - Perform Literature Search on Particle Dynamics of Glass & Beryllium
  - Create a 2D (AUTODYN 2D) model to Simulate a Single MM Impact On a Glass Disk
  - Using Data from a Single Test Case (small particle diameter, low velocity), Predict the Effect for a Larger Diameter, Faster Particle
  - Predict the Final Deformed Shape of a Glass Disk Subject to Both A Small/Slow & A Large/Fast Particle

Numerical Modeling Simulation (cont'd)

- Model's Predicted Damage Due To Large/Fast Particle Agreed With Historical Data (~20-30%)
- Model Over-Predicted the Physical Damage Done By Actual Particles at Auburn Test Facility by Large Factor (~5x)
- Deformation Predictions Still Under Review

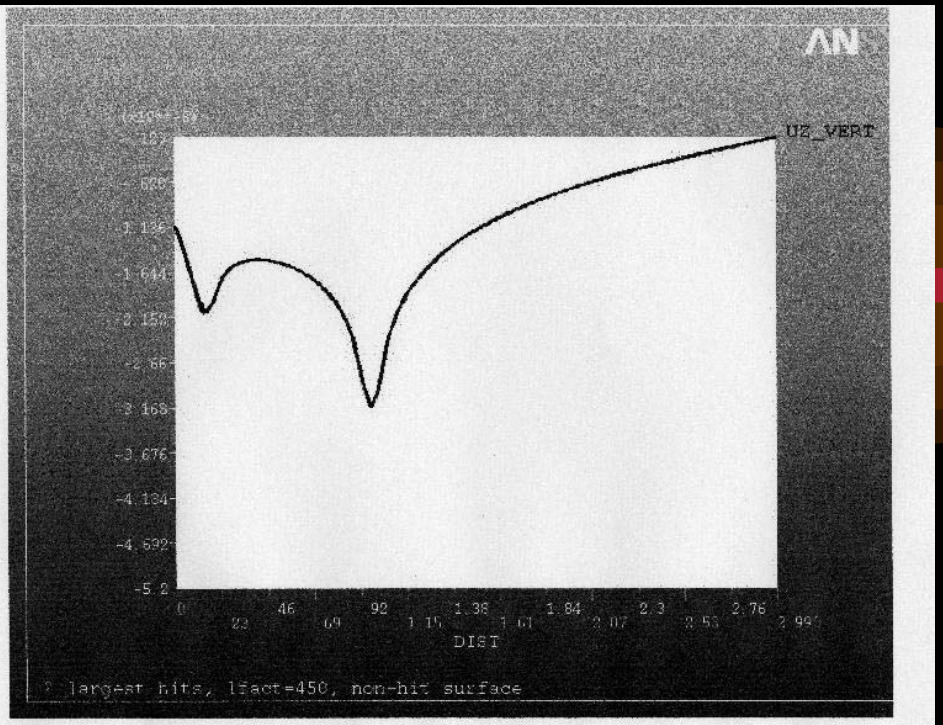
Predicted Surface Deformations

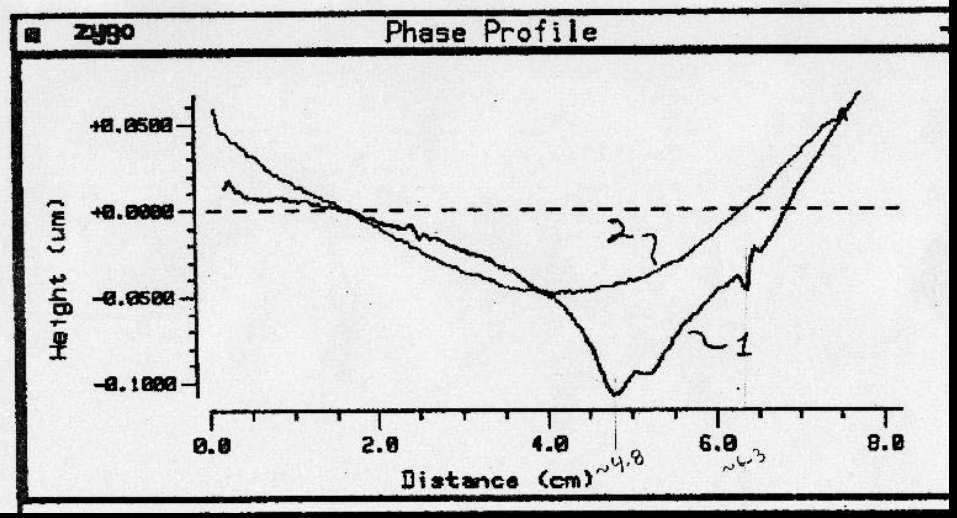




Finite Element Modeling of Two Micro-meteoroid Impacts

- We created a detailed 3d ANSYS FE model of the ULE sample.
- We did NOT model the actual crater damage
- To impart the “effective” stress in the damage, we created a surface layer which we could then “stress” (via a dT)
- We applied a scale-factor to the stress such that the P-V over the entire disk was correct
- We compared model results with interferometry results
- Results compared favorably
- We now need to perform this same analysis with other data


AN
UZ_VERT
-5.2
-4.692
-4.184
-3.676
-3.168
-2.66
-2.152
-1.644
-1.136
0
.46
.92
1.38
1.84
2.3
2.76
DIST
largest hits, lfact=450, non-hit surface


zygo
Phase Profile
+0.0500
+0.0000
-0.0500
-0.1000
Height (um)
0.0
2.0
4.0
6.0
8.0
Distance (cm)
~4.8
~6.3
2
1

Larger Scale Mirror Simulators

- Options Include
  - SBMD Mirror (sphere)
    - SBMD is not ideal because it is a sphere. Streak Camera needs to see the surface impact to get Velocity Data.
    - Therefore cannot calculate K.E. for Scale-Up
    - Flat Mirror is preferred.
  - 20-30cm Fused Silica & ULE Flats
  - Single Multi-Particle Shots With Metrology In Between
  - Total Cost: *Very Few* Tens of $K

Summary

- Testing and analysis to date indicates
  - Damage will be done to space mirrors at L2 but figure change *estimated to be in the few nanometer range*
    - *Probably NOT a problem*
  - Will Continue to Investigate to More Fully Quantify Effects